Associations of Body Composition with Type 2 Diabetes Mellitus

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The aims of this study were to establish the associations of stature, body mass index, waist to hip ratio, and waist circumference with Type 2 (non-insulin-dependent) diabetes mellitus in a random sample of 5887 men and 7018 women aged 20–59 years in a cross-sectional study set in The Netherlands. The crude prevalence of Type 2 diabetes (overall 1.58 % in men, 0.94 % in women) was significantly ($p < 0.01$) higher in shorter subjects and those with high body mass index, high waist to hip ratio, and larger waist circumference. Odds ratios and 95 % confidence intervals (95 % CI) were adjusted for age, cigarette smoking, alcohol consumption, physical activity, and education. Compared to the tallest tertile of height, odds ratios for Type 2 diabetes were 4.4 (95 % CI: 1.3 to 11.5) in men and 1.6 (95 % CI: 0.8 to 3.2) in women whose height was in the shortest tertile. Compared to the lowest tertile, odds ratios for Type 2 diabetes were 18.4 (95 % CI: 4.3 to 78.5) in men and 5.3 (95 % CI: 2.0 to 14.0) in women with waist to hip ratio in the highest tertile, 4.1 (95 % CI: 2.0 to 8.4) in men and 2.1 (95 % CI: 1.0 to 4.2) in women with body mass index in the highest tertile, and 4.9 (95 % CI: 2.1 to 11.7) in men and 2.7 (95 % CI: 1.2 to 5.9) in women with waist circumference in the highest tertile. In conclusion, although in longitudinal studies waist is a powerful predictor of diabetes incidence, Type 2 diabetes in a cross-sectional survey is associated with shortness in stature, as well as large waist circumference and high body mass index, and particularly strongly with high waist to hip ratio, suggesting that the development of Type 2 diabetes may modify hip circumference independently of body fat. © 1998 John Wiley & Sons, Ltd.

***Diabet. Med.* 15: 129–135 (1998)**

KEY WORDS **body composition; health promotion; height; skeletal muscle**

Received 12 February 1997; revised 10 June 1997; accepted 21 September 1997

Introduction

Type 2 (non-insulin-dependent) diabetes mellitus is a disease of nutrient storage and metabolism which associates with several other metabolic aberrations such as hyperlipidaemia and hypertension. Increased visceral fat mass is a major feature, possibly aetiologically important through increased fatty acid release into the portal system.[1,2] It is well established in cross-sectional studies that the measure of waist to hip ratio strongly associates with Type 2 diabetes.[3] This association has usually been interpreted as the result of central fat distribution, central obesity, upper body obesity, or truncal fatness. However, waist circumference is more highly predictive of intra-abdominal fat than waist to hip ratio,[4,5] and longitudinal studies have shown a stronger relationship between waist circumference and Type 2 diabetes development.[6–9]

Type 2 diabetes has also been suggested to be a consequence of developmental failure of vital organs, such as pancreas and liver, particularly in those exposed to poor nutrition at a critical stage of fetal development.[10] It is well established that short stature can reflect underdevelopment during the critical growth periods.[11]

The present study aimed to assess the prevalence and relative risks of Type 2 diabetes in relation to measures of body stature, body fatness, and fat distribution, in a cross-sectional survey of adults aged 20–59 years living in The Netherlands.

Methods

Subjects

In the present study, the 1993 to 1995 cohorts were available from the ongoing MORGEN (Monitoring of Risk Factors and Health in The Netherlands) project, which is undertaken as a public health surveillance to monitor chronic diseases, risk factors, and their consequences. Subjects were randomly recruited from

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Sponsors British Council, The Netherlands; Ministry of Public Health, Welfare and Sports of the Netherlands; Rank Foundation and Rank Prize Funds.

CCC 0742–3071/98/020129–07$17.50

civil registries of three towns, Amsterdam, Maastricht, and Doetinchem. The response rate to invitations was about 40 % in Amsterdam and 50 % in Maastricht and Doetinchem. To obtain similar numbers of subjects at each age, the sample was stratified by sex and five-year age group. The numbers of 5887 men and 7018 women aged 20–59 years in the present study represent those who attended the health centres for health assessments including anthropometric, physiological, and biochemical measurements. Those who did not attend or were not Dutch nationals were excluded.

Anthropometry

Anthropometric measurements were made according to the World Health Organization[12] recommendations by trained field scientists. Subjects wore light clothes during measurements of body weight to the nearest 100 g using calibrated scales, height without shoes to the nearest mm, waist circumference in duplicate at the level between the lowest rib margin and iliac crest to the nearest mm, and hip circumference at the widest trochanters to the nearest mm. Waist to hip circumferential ratio was computed, and body mass index was calculated as weight (kg) divided by height squared (m^2).

Definition of Type 2 (Non-insulin-dependent) Diabetes Mellitus

Subjects who reported to have been diagnosed with diabetes by a doctor and were not treated with insulin were considered as having known Type 2, non-insulin-dependent, diabetes mellitus (five men and nine women treated with insulin were not considered as having Type 2 diabetes). Subjects whose random non-fasting blood glucose concentration $\geq$ 11.1 mmol l^{-1} were considered as having newly diagnosed Type 2 diabetes.[13] The newly diagnosed diabetic subjects had had their last meal or drink (other than water) more than 6 h before their blood was taken. Known and newly diagnosed diabetes were combined for analyses. Non-fasting blood glucose was measured by World Health Organization standardized laboratory at the Academic Dijkzig Hospital of the Erasmus University in Rotterdam.

Statistical Methods

Statistical analyses were performed using SAS version 6.10 (Cary, USA). Tertiles were created for height, body mass index, waist to hip ratio, and waist circumference. The prevalence of Type 2 diabetes was determined for subjects in each tertile of anthropometry, using cross-tabulation with chi square statistic. Logistic regression analysis for unadjusted and adjusted for age and lifestyle factors was performed to estimate the relative risks (odds ratios and 95 % CI) of Type 2 diabetes in tertiles of height, body mass index, waist to hip ratio, and waist circumference. We have already demonstrated the lack of significant correlation between waist and height in these subjects for the 1993–1994 cohorts.[14,15] Thus waist to height ratio was not created as an index of adiposity. Height was entered in multivariate logistic regression analysis as independent variable in the associations of Type 2 diabetes with waist or with waist to hip ratio. Males and females were analysed separately.

Confounding Factors

Information on lifestyle and demographic factors were obtained from a self-administered questionnaire. Age was stratified by 10 year age categories; cigarette smoking was classified as non-smokers, ex-smokers, and current smokers; alcohol consumption as non-drinkers, occasional drinkers (less than one glass per day), moderate drinkers (one to two glasses per day), and heavy drinkers (three or more glasses per day); educational level as secondary education or lower, vocational or higher secondary education, and higher vocational education or university education; physical activity was classified as non-participants and participants in leisure time sports. In order to ascertain alcohol consumption, subjects were asked how many glasses of alcoholic beverages were consumed per week (separately for beer, wine, fortified wines and hard liquor). Responses were combined to obtain the total number of alcoholic beverages consumed per week.

Results

Table 1 shows that subjects with known Type 2 diabetes and those with newly diagnosed Type 2 diabetes were not significantly different in age. The diabetic subjects (known and new) were older, shorter, heavier, and they had higher body mass index, higher waist to hip ratio, and larger waist circumference than non-diabetic subjects. The median (quartile range) duration of known Type 2 diabetes was 2.2 (1.2 to 5.2) years in men and 4.6 (1.1 to 12.7) in women, and age of diagnosis was 47 (32 to 54) in men and 50 (43 to 54) years in women.

Tables 2(a) and 2(b) show that the unadjusted prevalence of Type 2 diabetes was relatively high in categories of short stature, higher body mass index, higher waist to hip ratio, and larger waist circumference as well as older age (Figure 1). In both sexes, compared to lowest tertile (or highest tertile in the case of height) the age adjusted odds ratios for Type 2 diabetes were significantly higher in the shortest tertile of height, third tertile of waist to hip ratio, body mass index, and waist circumference. Table 3 shows that after additional adjustment for cigarette smoking, alcohol consumption, educational level and physical activity, the strength of the associations was slightly reduced, and the relationship between Type 2 diabetes and height in women became non-significant.

When height was entered into multiple logistic regression model with waist to hip ratio, or with waist

Table 1. Characteristics of subjects with known Type 2 diabetes, newly diagnosed Type 2 diabetes (random blood glucose concentration ≥ 11.1 mmol l^{-1}), and non-Type 2 diabetic subjects

	Known Type 2 diabetes		Newly diagnosed Type 2 diabetes		Non-Type 2 diabetic subjects	
	Mean	SD	Mean	SD	Mean	SD
Men	($n = 63$)		($n = 30$)		($n = 5794$)	
Age (yr)	51.1	7.2	53.1	5.6	42.7	10.7
Weight (kg)	85.6	15.8	97.2	18.4	81.9	11.9
Height (cm)	173.1	6.6	176.4	7.4	178.5	7.2
Body mass index (kg m^{-2})	28.5	4.5	31.2	5.2	25.7	3.5
Waist circumference (cm)	100.0	12.5	111.2	14.0	92.1	10.6
Hip circumference (cm)	102.1	8.7	109.4	12.7	101.7	6.5
Waist to hip ratio	0.977	0.057	1.017	0.064	0.904	0.071
Women	($n = 51$)		($n = 15$)		($n = 6952$)	
Age (yr)	50.8	8.1	51.8	8.3	42.1	10.9
Weight (kg)	79.3	16.3	71.9	16.6	68.4	11.4
Height (cm)	162.9	5.9	159.7	5.9	165.7	6.7
Body mass index (kg m^{-2})	29.9	6.3	28.2	6.4	24.9	4.1
Waist circumference (cm)	96.7	15.2	92.3	14.2	80.9	10.9
Hip circumference (cm)	108.5	13.0	103.5	13.2	102.2	8.3
Waist to hip ratio	0.891	0.091	0.891	0.072	0.790	0.069

Table 2. (a) Crude prevalence and age adjusted odds ratios for Type 2 diabetes in different tertiles of anthropometry, in 5887 men

	Prevalence ($n = 93$[b])	OR	95 % confidence interval
Height tertile 3 (≥ 181.5 cm)	0.60	1.00	–
Height tertile 2 (175.0–181.3 cm)	1.64	3.19[a]	1.20, 8.49
Height tertile 1 (< 174.8 cm)	2.61	5.13[a]	1.98, 13.26
χ^2[c]	24[a]		
Waist to hip ratio tertile 1 (< 0.872)	0.10	1.00	–
Waist to hip ratio tertile 2 (0.872–0.936)	0.66	4.07	0.90, 18.52
Waist to hip ratio tertile (≥ 0.936)	3.98	19.70[a]	4.65, 83.51
χ^2[c]	111[a]		
Body mass index tertile 1 (< 24.1 kg m^{-2})	0.46	1.00	–
Body mass index tertile 2 (24.1–26.9 kg m^{-2})	0.87	1.30	0.57, 2.94
Body mass index tertile 3 (≥ 26.9 kg m^{-2})	3.41	4.40[a]	2.16, 8.95
χ^2[c]	65[a]		
Waist circumference tertile 1 (< 86.9 cm)	0.32	1.00	–
Waist circumference tertile 2 (87.0–95.9 cm)	0.98	1.89	0.75, 4.81
Waist circumference tertile 3 (≥ 96.0 cm)	3.33	5.22[a]	2.21, 12.34
χ^2[c]	64[a]		

[a]$p < 0.001$.
[b]Number of subjects with Type 2 diabetes.
[c]Difference in prevalences between tertiles.

circumference as an independent variable, there were no substantial changes to the odds ratios (within 0.1 unit) of either height, waist to hip ratio or waist circumference, and all independent variables remained significantly related to Type 2 diabetes. Excluding the 30 men and 15 women who were newly diagnosed did not change the results (within 0.1 unit of odds ratios: results not presented).

Discussion

The present study lends support to previous findings for the associations between high waist to hip ratio, high body mass index, and large waist circumference with Type 2 diabetes, hyperglycaemia, and insulin resistance.[1,2,16–18] After age adjustment, shorter men were five times more likely and shorter women were twice as likely to have Type 2 diabetes compared to taller subjects. Shorter men remained to associate significantly with Type 2 diabetes even after the additional adjustments were made for educational level, smoking, and physical activity level, suggesting that this association was independent of educational level and lifestyle factors.

Our findings support previous studies of Brown *et al.* who have observed negative correlations betwen glucose tolerance and height,[19] and that of Mooy *et al.* who

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Table 2. (b) Crude prevalence and age adjusted odds ratios for Type 2 diabetes in different tertiles of anthropometry, in 7018 women

	Prevalence ($n = 66^{d}$)	OR	95 % confidence interval
Height tertile 3 (≥ 168.5 cm)	0.49	1.00	–
Height tertile 2 (163.0–168.0 cm)	0.80	1.31	0.63, 2.74
Height tertile 1 (<162.5 cm)	1.55	2.07[c]	1.06, 4.04
χ^{2e}	15[b]		
Waist to hip ratio tertile 1 (< 0.756)	0.21	1.00	–
Waist to hip ratio tertile 2 (0.756–0.815)	0.30	1.05	0.33, 3.38
Waist to hip ratio tertile 3 (≥ 0.815)	2.31	6.27[a]	2.40, 16.41
χ^{2e}	71[a]		
Body mass index tertile 1 (< 22.8 kg m^{-2})	0.51	1.00	–
Body mass index tertile 2 (22.8–25.9 kg m^{-2})	0.34	0.52	0.21, 1.32
Body mass index tertile 3 (≥ 25.9 kg m^{-2})	2.01	2.47[c]	1.24, 4.90
χ^{2e}	43[a]		
Waist circumference tertile 1 (< 75.0 cm)	0.35	1.00	–
Waist circumference tertile 2 (75.0–84.0 cm)	0.39	0.78	0.28,2.04
Waist circumference tertile 3 (≥ 84.0 cm)	2.03	3.16[b]	1.44, 6.96
χ^{2e}	47[a]		

[a]$p < 0.001$, [b]$p < 0.01$, [c]$p < 0.05$.[d]Number of subjects with Type 2 diabetes.
[e]Difference in prevalences between tertiles.

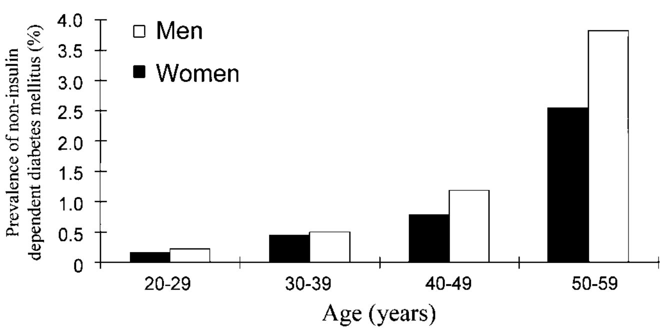

Figure 1. The prevalence of Type 2 diabetes mellitus by decades of age

have shown that shortness of stature was a significant determinant of glucose intolerance.[20] Other studies of men showed similar patterns in the association of shorter height with low insulin response,[21] known,[22] newly diagnosed Type 2 diabetes[22,23] and glucose intolerance.[23] A study of European and Asian men found no differences in height between those with normoglycaemia, impaired glucose tolerance and Type 2 diabetes.[24] The present study found stronger associations between short stature and Type 2 diabetes in men than in women. It is possible that taller non-diabetic women might have had relatively more height shrinkage than the shorter diabetic women.[25] Since both short stature[11] and Type 2 diabetes[10] reflect reduced development during the critical periods of

Table 3. Odds ratios for Type 2 diabetes in different tertiles of anthropometry, adjusted for age, smoking, alcohol consumption, physical activity, and education, in 5887 men and 7018 women

	Men ($n = 93^{d}$)		Women ($n = 66^{d}$)	
	OR	95 % confidence interval	OR	95 % confidence interval
Height tertile 3	1.00	–	1.00	–
Height tertile 2	3.07[c]	1.70, 8.16	1.25	0.60, 2.62
Height tertile 3	4.42[b]	1.26, 11.51	1.62	0.82, 3.18
Waist to hip ratio tertile 1	1.00	–	1.00	–
Waist to hip ratio tertile 2	4.16	0.91, 19.00	0.98	0.31, 3.14
Waist to hip ratio tertile 3	18.36[a]	4.29, 78.49	5.31[a]	2.02, 13.96
Body mass index tertile 1	1.00	–	1.00	–
Body mass index tertile 2	1.34	0.59, 3.06	0.52	0.21, 1.30
Body mass index tertile 3	4.07[a]	1.98, 8.35	2.07[c]	1.03, 4.19
Waist circumference tertile 1	1.00	–	1.00	–
Waist circumference tertile 2	1.93	0.76, 4.94	0.75	0.28, 1.98
Waist circumference tertile 3	4.92[a]	2.07, 11.70	2.67[c]	1.20, 5.91

[a]$p < 0.001$, [b]$p < 0.01$, [c]$p < 0.05$.
[d]Number of subjects with Type 2 diabetes.

growth, these factors may be linked in the aetiology of Type 2 diabetes. Early growth underdevelopment, reflected by low birth weight, has been shown to associate with high waist to hip ratio in men[26] and increased waist circumference in women.[27] All these adverse anthropometric measures are characteristics of poor health. Barker *et al*. have shown that shorter populations have higher risks of mortality from cardiovascular disease, chronic bronchitis, and cancers in men and women.[28] A study of diabetes in rural Tanzania has shown that the prevalence of impaired glucose tolerance, but not diabetes, tended to be higher in shorter men and shorter women.[29] According to the thrifty phenotype hypothesis,[30] the absolute risk of diabetes for shorter subjects in the study of Swai *et al*.[29] would not be great, since rural Tanzanians were not exposed to overnutrition.

Several findings point towards an important role of skeletal muscle in the association between altered body morphology and related diseases such as Type 2 diabetes. The prevalences of overweight[31] and associated Type 2 diabetes in Pima Indians are among the highest in the world,[32] and Fontvieille *et al*. have shown that Pima Indian children are less physically active than Caucasian children.[33] In a study of 24 healthy men, Seidell *et al*. have shown that those with increased waist to hip ratio had relatively less thigh muscle, raised insulin and decreased muscle endurance.[34] The link of diabetes with reduced oxidative muscle fibres is established.[35] Exercise training can prevent muscle atrophy and increase muscle mass, and endurance exercise training can alter muscle morphology towards higher oxidative capacity by increased vascularization, increased oxidative enzymes and mitochondrial density,[36] upregulation of insulin receptors, and increased insulin sensitivity.[37] It has been suggested that regular exercise may prevent the development of Type 2 diabetes.[38]

Our observations of greater risk of Type 2 diabetes in shorter people, particularly men, even after adjusting for age, lifestyle factors, and body fat distribution is in broad agreement with the findings of Barker's group.[39] A possible mechanism would be the alterations in mass of metabolically important tissues—particularly skeletal muscle. Indeed, high waist to hip ratio was most strongly related to Type 2 diabetes in the present cross-sectional study. If intra-abdominal fat were the only influence on development of Type 2 diabetes, then waist circumference alone should be at least as strongly associated with Type 2 diabetes as waist to hip ratio, since the waist reflects intra-abdominal fat[4,5] while hip circumference includes contributions from both the bony pelvis and also the truncal muscles, which make up one of the main organs for glucose metabolism and insulin action.[40] In a cross-sectional study, Hartz *et al*. found that waist circumference was positively and hip circumference was negatively associated with diabetes in women.[41] In the same sample of subjects from our present study,[42] we found that subjects with larger waist measurements or smaller hip circumference than expected from their body mass index had higher risk of Type 2 diabetes. We suggested that increased intra-abdominal fat might precede the development of Type 2 diabetes, and muscle atrophy might follow, since insulin action and glucose clearance are related similarly[43] or more highly with waist circumference than with waist to hip ratio in non-diabetic subjects.[18] This could explain the consistently different associations of waist circumference and waist to hip ratio with Type 2 diabetes in longitudinal and cross-sectional studies. Ohlson *et al*. have shown that waist circumference was at least strong as waist to hip ratio in predicting the development of Type 2 diabetes over 13.5 years in men.[6] A 5-year follow-up study in men confirmed these findings,[7] and recent prospective studies also found that waist circumference was better than waist to hip ratio in the prediction of Type 2 diabetes.[8,9] Lemieux *et al*. found that 7-year changes in indices of glucose-insulin homeostasis were related to changes in visceral fat and waist circumference, but not to waist to hip ratio in non-diabetic women.[44] These findings suggest that it is possible that large waist circumference predicts the development of Type 2 diabetes, while muscle loss leads to decreased hip circumference measurement when Type 2 diabetes develops. Thus waist to hip ratio would be a better marker of existing Type 2 diabetes, while waist circumference would better predict future disease. These interpretations are complicated by different levels of precision in anthropometric measurements, which could introduce a correlation dilution effect.

One of the limitations of the present study is that Type 2 diabetes was self-reported. Lesser degrees of hyperglycaemia might have been missed. However, analyses with newly diagnosed diabetic subjects included in the non-diabetic group did not substantially change the results. Furthermore, the use of tertiles in logistic regression analysis will have underestimated the strength of the relationships between variables.

Conclusion

We conclude that, although in longitudinal studies waist is at least as powerful as waist to hip ratio in predicting diabetes incidence, Type 2 diabetes in a cross-sectional survey is associated with shortness in stature, large waist circumference, and high body mass index, and is particularly strong with high waist to hip ratio. These data suggest that the development of Type 2 diabetes may modify hip circumference independently of body fat.

Acknowledgements

We are grateful to Anneke Blokstra for data management. The authors would like to thank the Municipal Health Services in Amsterdam, Doetinchem, and Maastricht for their important contribution to the data collection for this study. This work was funded by The British Council,

The Netherlands (TSH), Ministry of Public Health, Welfare and Sports of The Netherlands (EMJF and JCS), Rank Foundation and Rank Prize funds (MEJL). Conflict of interest: none.

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